iTRAQ - An Integrated Traffic Management and Air Quality Control System Using Space Services

Benjamin N. Passow, David Elizondo, Eric Goodyer
De Montfort University's Interdisciplinary Group in Intelligent Transport Systems (DIGITS)
De Montfort University
Leicester, LE1 9BH, United Kingdom
benpassow@ieee.org, elizondo@dmu.ac.uk, eg@dmu.ac.uk

Roland J. Leigh, James P. Lawrence
Earth Observation Science, Space Research Centre, Department of Physics and Astronomy
University of Leicester
Leicester, LE1 7RH, United Kingdom
rl40@leicester.ac.uk, jl110@leicester.ac.uk

Satish Shah, Jolanta Obszynska
Leicester City Council
Leicester, LE1 6ZG, United Kingdom
satish.shah@leicester.gov.uk, Jolanta.Obszynska@leicester.gov.uk

Sarah Brown
Astrium GEO-Information Services
Leicester, LE3 1UT, United Kingdom
sarah.brown@infoterra-global.com

Stefan Gustafsson, Norbert Huebner
Integrated & Telecom related Applications Department
European Space Agency
2200 AG Noordwijk, the Netherlands
Stefan.Gustafsson@esa.int, Norbert.Huebner@esa.int

Full Paper — **There is a strong need for local authorities to meet the challenges of sustainable transport as well as complying with air quality targets. iTRAQ - Integrated Traffic Management and Air Quality using Space Services is a European Space Agency funded project. During the course of a feasibility study a consortium of UK industry, academic and local authority partners developed and validated a dynamic system for optimising the use of the road network balanced with the need to sustain high standards of air quality.**

iTRAQ uses a number of inputs that enable it to sense the current situation in near-real-time and provide accurate forecasts using a computational intelligence module. Traffic flow, queues, and congestion are gathered using traditional ground-based sensors as well as Global Navigation Satellite Systems based vehicle data. Air quality information is obtained from in situ monitors, a City-wide Gaussian dispersion model (Airviro), a European-scale ensemble model (MACC), and direct measurements from low-earth orbit satellites (OMI and GOME-2).

The concept has been tested and validated using near-real-time data and a simulation environment, providing enhanced strategies to the local authority. Following a successful feasibility study, a larger demonstration phase is now being planned and other local authorities are being encouraged to participate. This paper gives an overview of this novel system and presents some initial test results that confirm the feasibility of this integrated system, reducing the traffic delay, increasing the flow and optimising the local air quality levels.

Intelligent Transport, Mobility, Traffic Management, Air Quality, NO_2, Sustainability, Computational Intelligence, Earth Observation, Urban Traffic Management and Control

I. INTRODUCTION

The iTRAQ project has developed a dynamic traffic management system for optimising use of the road network whilst meeting growing demands, from Governments across the United Kingdom (UK) and Europe and from the European Commission, to sustain high standards of air quality in urban environments. The project was funded by the European Space Agency's Integrated Applications Promotion (IAP) Programme and comprises a consortium of industry, academic and local authority partners whose combined expertise includes intelligent traffic management systems using Global Navigation Satellite Systems (GNSS), air quality applications using Earth Observation (EO) and other Global Monitoring for Environment and Security (GMES) technologies.

Traditionally, air quality and traffic management issues have been considered in isolation. One of the key novel aspects of iTRAQ is that it integrates these two elements to create a coherent optimised system for both traffic management and air quality. This paper presents details and results from a Proof of Concept that was part of a feasibility study of the iTRAQ system and service undertaken in 2011.

The overall objectives of the feasibility study were as follows:

- To identify and define the user requirements.
- To design a system architecture which addresses service definition requirements.
- To demonstrate feasibility of a near-real-time iTRAQ architecture, providing integrated decision-making tools for traffic and air quality control.
- To identify any technical limitations constraining the iTRAQ system, and propose solutions.
- To consult potential end-users to establish the value of the demonstrated performance.
- To investigate the financial, legal, and regulatory feasibility including commercial viability and operational sustainability of the iTRAQ service.
- To prepare a roadmap towards demonstrating a fully operational and integrated system.

This paper will focus on the technical aspects of the feasibility study, introducing the iTRAQ architecture, describing data feeds, and presenting trial results. A near-real-time study was performed as a Proof of Concept to demonstrate the coordinated use of necessary data products and processing chains, to an extent sufficient to prove fundamental feasibility. In the process a number of technological and operational challenges were identified and resolved.

A region of interest was determined within the city of Leicester, UK, to trial the iTRAQ service during September and October 2011. The objective of the feasibility trial was to deliver traffic condition and air quality forecasts as well as traffic light sequencing recommendations on two junctions within the region of interest, resulting from a computational intelligence decision-making process using the traffic and air quality forecasts. The core Computational Intelligence (CI) system was created by De Montfort University, with air quality inputs delivered by the University of Leicester. Congestion-mapping technology was developed by De Montfort University, with in situ road induction loop data used in place of GNSS inputs for this feasibility study. Air Quality inputs were gathered from in situ monitors, a city-wide Gaussian dispersion model (Airviro), a European-scale ensemble model (MACC), and direct measurements from low-earth orbit satellites (OMI and GOME-2). The overall system was tested on real data, in near-real-time, and in simulation.

The rest of the paper is organized as follows: Section II presents background information and related research on urban traffic management and control as well as air quality management. Section III introduces the iTRAQ system architecture and its data feeds. Section IV provides details on the near-real-time tests that have been conducted in the city of Leicester, UK. Section V presents results from experiments testing the proposed system while final conclusions are drawn in Section VI.

II. Background

A. *Urban Traffic Management and Control*

A common way of dealing with large urban transport infrastructures is by using Urban Traffic Management and Control (UTMC) systems [1][2]. The UK Department for Transport led Urban Traffic Management and Control initiative recognises the following common UTMC components: strategic network management, comprehensive performance monitoring, traveller information, congestion monitoring, streamlined fault management, and consolidated asset management [3].

A first approach to controlling the traffic in an urban environment involves the analysis of the environment to generate a static model for specific times such as the morning (AM) peak and evening (PM) peak. These static models are then used to plan traffic light signalling scenarios [4].

The UTMC collects information about the current situation in the urban environment, such as traffic flow and delay via inductive street loops, car park information, and CCTV feeds from throughout the city. This information is made available to traffic engineers monitoring and managing the network. They can then influence the network by implementing alternative traffic light signalling strategies, informing drivers via variable message signs or on-line or radio information services. Engineers can resolve or ease situations during peak hours, or in the event of car accidents, full car parks, large fires, congestion, special events, etc.

Although in theory the collected information enables the traffic engineers to react to a variety of situations, most often, only a few standard traffic light configurations are used for any region in the urban environment. This is because traffic light signalling in a large urban network is an extremely difficult task where a small change can have a big impact on the whole network [4].

Standard traffic light signalling configurations are carefully designed using a variety of techniques from modelling, micro-simulation, macro-simulation, and ``green wave'' offset adaptation [5][6]. These static models are then manually revised over time from experience of the traffic engineer. Systems such as SCOOT further adapt some aspects of the traffic light signalling [7].

Subject areas of traffic management employing Artificial Neural Networks (ANN), a CI technique, include: forecasting, management, monitoring, modelling, control and routing [8]. A vast amount of research has been done on the use of ANN for traffic forecasting. A comparison of ANN methods in a study aimed at optimising their performance in forecasting vehicle speed is presented in [9]. A useful contribution of this work is the incorporation of a long-term memory component into the input data patterns to help the ANN recognise recurrent patterns that emerge on a day-to-day basis.

B. *Air Quality Management*

Atmospheric constituents which have the potential to harm human health are generally referred to as air pollution. In the UK urban environment there are a range of pollutants in the atmosphere with the capacity to cause harm to both humans and the ecosystem on which we depend, including carbon monoxide, nitrogen oxides, sulphur dioxide, particular matter, volatile organic compounds, ozone and hydrocarbons. Many of the aforementioned gases are either harmful to the human respiratory system and/or potentially carcinogenic [10].

Within the UK, as in the rest of Europe, air quality directives are cascaded down from the European Union, providing a structured framework of compliance levels for key pollutant species. The UK government and its local authorities operate a number of systems for monitoring and predicting air pollution, including automatic and manual air pollution monitors, emission inventories and a number of computer models including ADMS-Urban, the national model and the UK Integrated Assessment Model (UKIAM). These tools are used to inform policy makers and developers of the impact of various strategies in order to help reduce air pollution and the population's exposure to it.

The UK government currently operates over 300 national air quality monitoring sites to monitor and manage ambient pollutant concentrations [11]. Air pollution in urban environments remains high on the agenda for the government and local authorities, particularly given increasing urban populations and greater congestion on the already overcrowded traffic network. Recent epidemiological studies suggest that at present air pollution results in an average 7 month reduction in life expectancy and costs UK society up to £20 billion per year [12].

A number of mitigation measures for the air quality problem (relocating power stations, scrubbing their emissions and residential homes changing from burning coal to central heating) have already been implemented. As a result the reduction in atmospheric pollution has slowed over the last decade and in some instance may have begun to increase (particular matter) [13][14]. Measures to improve air quality on the local scale are now very much focused on optimisation of traffic network utilisation by promoting cycling through cycle lanes, and public transport through park and ride services and bus lanes. In addition strict requirements on vehicle emissions filtered down from the EU and a road tax system focused on vehicle emissions have helped to reduce air pollution from traffic (although to a lesser extent than expected). Despite this however the steadily increasing volume of traffic on city roads is believed to be partly compensating for this improvement [12].

Despite the local, national and European objectives to improve air quality the majority (40/43) of the UK's regulation zones are failing to meet the EU standards on at least one of the regulated gases. As such additional and alternative approaches to improving air quality must be adopted, and one such approach is the optimisation of the traffic system with air quality as one of the driving elements (iTRAQ).

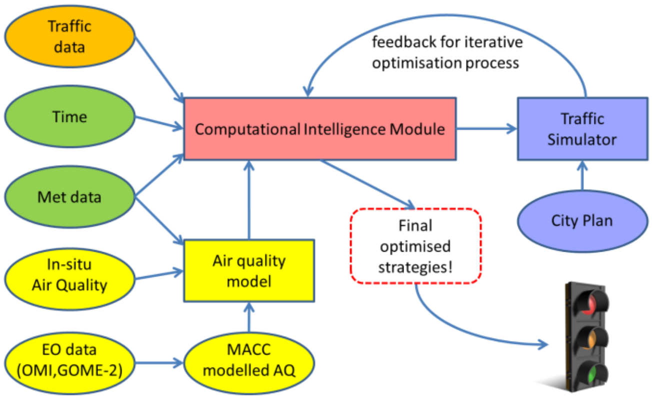

Figure 1. Overview of the modular iTRAQ architecture with data feeds.

III. The iTRAQ Architecture

The iTRAQ demonstration system comprises a series of autonomous data feeds (data transfer mechanisms) between computer servers at the University of Leicester, De Montfort University and Leicester City Council. The network of data feeds and the computer algorithms which produce and manipulate the data are known collectively as the iTRAQ system architecture.

The iTRAQ system has been designed around a CI module made of a series of advanced neural networks and genetic algorithms for finding the optimal traffic and air quality solution for Leicester City. Many of the data feeds in the iTRAQ system are designed to provide information to the CI or to transfer results from the CI to a series of analysis algorithms to assess the performance of the system. The data feeds that go into the CI are formatted using the NASA Ames file formatting standard to ensure all relevant information regarding the data feed is carried within the file and to provide compatibility between all iTRAQ partners. The iTRAQ architecture has evolved throughout the iTRAQ feasibility study with changes being made to both the source of information and the methodology used for manipulating and interpreting the data. The resulting architecture is shown in Fig. 1 and described here in more detail.

The iTRAQ system uses a variety of data feeds together with a CI module, air quality model and traffic simulator, to arrive at an optimised strategy for traffic and air quality management.

A. *Traffic data*

The current traffic conditions throughout the urban environment need to be known in order to accurately forecast the next time intervals conditions. The most prevalent form of traffic monitoring is the inductive loop, a loop embedded in the road surface capable of detecting vehicles passing over it. GNSS derived information on the other hand is not restricted to specific main roads within the network. Near-real-time information from a large fleet of GNSS enabled vehicles is generally commercially available. Often such information is also present in urban environments through near-real-time public transport information systems.

This research has been planned with the use of GNSS data from Leicester's public transport information system called Star-Trak. Unfortunately, this system was taken offline at the start of the practical research due to a lack of funding. For this reason, GNSS data was replaced with in situ monitors for traffic monitoring.

B. Time

Within the CI core module there are traffic condition and air quality forecasters. These need a time stamp as part of their input to predict future values. More specifically, the forecasters use two time based inputs: hour-of-day as well as day-of-week.

C. Meteorological data

Traffic conditions as well as air quality depend on meteorological conditions [15]. For example, heavy rain can slow down traffic flow and it cleans the air from pollutants. Here, a variety of local meteorological information is used by the forecasters:

- Temperature
- Cloud Coverage
- Air Pressure
- Precipitation
- Wind Speed
- Wind Direction

All these near-real-time readings are used to forecast traffic conditions as well as the air quality in the urban environment.

D. Air quality model

In the iTRAQ feasibility study Nitrogen Dioxide (NO_2) is used as a tracer for pollution as it correlates well with other emissions from vehicles and is frequently measured by in-situ monitors.

Airviro is an atmospheric dispersion model providing two dimensional maps of atmospheric pollution with a high spatial resolution enabling NO_2 emissions from individual roads and junctions to be resolved. There are a number of dispersion models available within Airviro, including a grid mode, an idealised street canyon mode, a heavy gas mode and a Gaussian dispersion mode. For the purposes of simulating emissions from road traffic on a city wide scale the Gaussian dispersion mode is considered to be the most suitable method.

The Airviro dispersion model is the primary source of air quality information passed to the CI. A near real time (NRT) Gaussian dispersion product of the Airviro model operating at 100 m spatial resolution and one hour temporal resolution was made available to the iTRAQ project known as the 'nowcast' and was used for the duration of the trial phase. Fig. 2 presents an example of the nowcast output as a map of NO_2 concentrations over Leicester City.

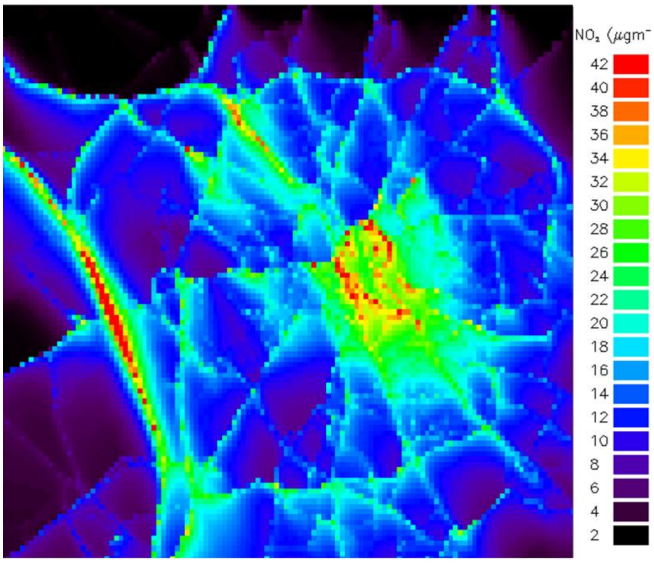

Figure 2. Example of Airviro nowcast (6th Oct. 2011, 09:00) as a map of NO_2 concentrations over the city of Leicester, UK, with a stretch of the M1 motorway (left).

E. Earth Observation enhanced Air Quality model

Throughout the iTRAQ study a number of systems have been tested to introduce Earth Observation (EO) data as a source of information to improve the accuracy and expand on the content of air quality information provided to the CI and Airviro. The data feed assignments have remained the same throughout the architectural changes but their application has altered significantly. Prior to iTRAQ it was unknown precisely how useful satellite remote sensing data would be to local air quality concerns and a number of data sources were investigated leading to two live data feeds of NO_2 products from the Ozone Monitoring Instrument (OMI) and Global Ozone Monitoring Experiment-2 (GOME-2) satellites being acquired.

The OMI is a remote sensing instrument on board NASA's AURA satellite which uses the Differential Optical Absorption Spectroscopy (DOAS) method of retrieving the concentration of atmospheric constituents using scattered sunlight from the Earth's surface. The AURA/OMI overpass time is approximately 1.30 pm, providing a single view of the NO_2 concentrations over Leicester with a spatial resolution of 13 by 24 km.

GOME-2 is a remote sensing instrument on board ESA's EUMETSAT Meteorological Operational Satellite (MetOp-A) which uses the DOAS methodology to retrieve total column measurements of various atmospheric gases including NO_2. Being onboard MetOp-A GOME-2 has a local overpass time of approximately 9.00 am, providing a single atmospheric measurement over the region of interest once or twice per day with a spatial resolution of approximately 80 by 40 km.

It was found over the course of a number of months that the large pixel size and frequent obstruction by cloud cover rendered OMI and GOME-2 satellite measurements unsuitable for direct inclusion into an operational system. To provide background atmospheric concentrations of NO_2, an alternative system was introduced based on a series of atmospheric transport models operated by the Monitoring Atmospheric Composition and Climate (MACC) program.

The MACC is a European GMES program comprising of 45 national institutes including the European Centre for Medium Range Weather Forecasting (ECMWF) and the Joint Research Centre (JRC). For iTRAQ the atmospheric modelling product known as the ensemble product is used as a source of background NO_2 data to complement the local air quality Airviro model. The ensemble data product comprises of seven regional air-quality analysis and forecasting systems constrained by assimilated EO data providing air-quality forecasts up to 72 hours from each model run. The models that are used within the ensemble are CHIMERE, EMEP, EURAD, LOTOS-EUROS, MATCH, MOCAGE and SILAM. The EO data sources which are assimilated into the ensemble models for the NO_2 forecasts are atmospheric column retrievals of NO_2 from AURA/OMI, METOP/GOME-2 and ENVISAT/ SCIAMACHY.

Access to MACC data for use in the iTRAQ study was kindly granted. Automatic scripts running on a computer server at the University of Leicester were written to routinely download the MACC data from the SFTP site and to interrogate the files for the UK forecasts of NO_2 at ground level. This information was then fed to the CI module to forecast the air quality and traffic conditions and react to these accordingly.

F. Traffic Simulator

In this work, the macro-simulator SATURN was used to evaluate traffic and air quality strategies. This simulator was originally developed by the University of Leeds and commercialised by Atkins since 1981. It is a combined traffic simulation and assignment model that can handle very large networks of up to 37500 junctions while being suitable for the analysis of very minor network changes e.g. to adapt traffic light signalling strategies.

G. Computational Intelligence Module

CI stands for a number of algorithms that provide powerful means to handle data and systems more intelligently. These methods include Artificial Neural Networks (ANN) and Evolutionary Algorithms (EA), both of which are used in the iTRAQ CI.

The iTRAQ CI core module consists of traffic and air quality ANN based predictors as well as EA based optimisation techniques to identify traffic management strategies that best enhance the forecasted traffic conditions and air quality.

IV. NEAR-REAL-TIME TEST RUNS

The primary objective of the iTRAQ project is to provide an improved decision-making tool to local authorities, through integrated traffic and air quality information

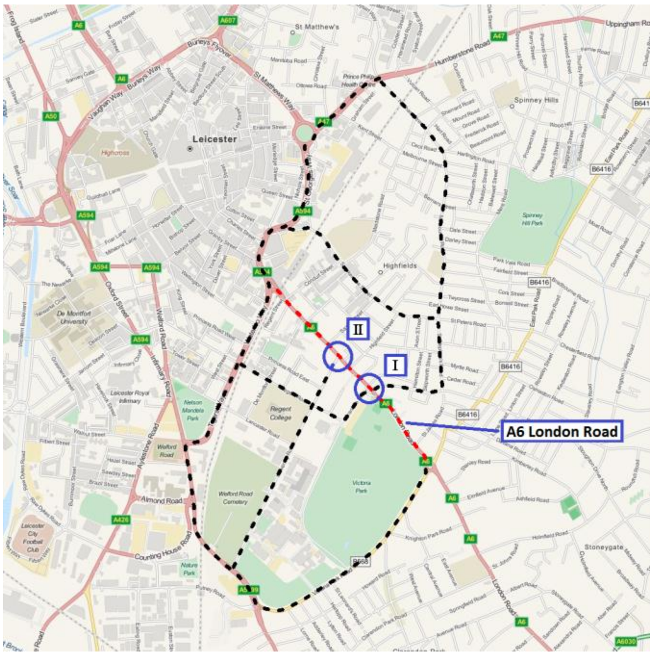

Figure 3. Region of interest in the city of Leicester, United Kingdom. Marked road is the A6 London Road, a mayor link within Leicester, UK. Map data © OpenStreetMap contributors, CC BY-SA

systems. Such integrated information and advice systems rely on a comprehensive network of monitors and data processing units to deliver an end-product. The proof of concept study was designed to demonstrate the coordinated use of necessary data products and processing chains, to an extent sufficient to prove fundamental feasibility, in the process uncovering and resolving potential technological and operational challenges.

A. Region of Interest

In order to test the proposed system, a region of interest has been chosen. Fig. 3 shows the region, which consists of 20 roads around the A6 London Road in the city of Leicester, UK. The A6 is a major arterial road for the city that regularly experiences large amounts of traffic, reduction of flow, increase in delay, and congestion. This particular road has been subject to previous research in traffic as well as air quality optimisation [16] [17].

B. Junctions to optimise

Within the region of interest, two junctions were selected for the analysis. These junctions are two major intersections along the A6 London Road. The majority of the analysis and optimization work was focused on the junction labelled “I” in Fig. 3. This is a major junction within the region of interest, with air quality issues impacting on a mixture of commercial premises, residential areas, and the recreational area of Victoria Park. Fig. 4 shows the bigger of the two junctions (“I” in Fig. 3) optimised in this work together with their traffic light signal stages and default timings for the AM and inter-peak periods.

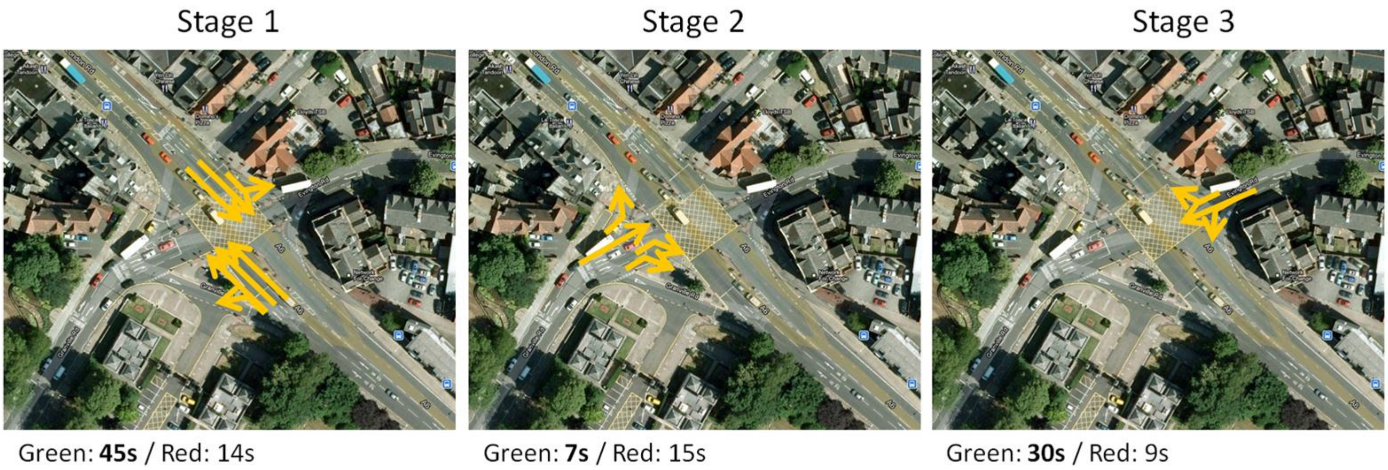

Figure 4. Traffic light signal stages with their default timings for AM (morning) and inter-peak periods, for one junction on the A6 London Road, as optimised in this work. (Background image source: Google Earth, Infoterra)

C. *Constraints*

As is typical for a feasibility study, there have been a number of constraints on testing the operational iTRAQ system. The system was tested in near-real-time proposing optimised strategies to Leicester City Council for over two weeks. The following constraints were deemed acceptable for the purpose of testing the feasibility of the overall iTRAQ system.

- The system was operational from Monday to Friday from 07:00 to 17:00 each day.
- The system suggested optimised traffic and air quality strategies within one hour.
- The traffic signalling strategies of two junctions were optimised, suggesting cycle times, individual stage times, and offsets for both junctions.
- Due to a lack of GNSS data from the Star-Trak public transport information system, only in-situ street loop based traffic data was used.
- The system has been tested on junctions of a major arterial road. As such, during this feasibility study, no strategies were directly tested on the junctions but in simulation only. Nevertheless, actual near-real-time data feeds were used to test the operational system as if it would be fully integrated and operational, providing optimised traffic signalling strategies to the traffic engineers in near-real-time.

The iTRAQ system has been tested and the quality of the forecasts as well as the proposed optimised strategies has been evaluated.

V. RESULTS

A. *iTRAQ Stability*

The NRT iTRAQ system has been run for over two weeks, using live data from various sources. The system run stable with only minor programming issues, even in the presence of noisy and unreliable data. In total there were two failures of the input data streams, one of which was a user error and the other an unrelated traffic control system failure. The planned integration of GNSS based traffic condition data can augment, and in case of another failure replace the induction-loop based traffic data. In total, counting all actual NRT runs of the iTRAQ system, 101 out of 104 runs were completed successfully. The causes for the three crashes were programming issues that have already been resolved in the latest version of the iTRAQ system.

B. *Traffic Condition Forecasts*

The forecasts are directly vital parts of the iTRAQ system, as well as important outputs for the users. The quality of the outputs is relative to the quality of the inputs and the amount of training data.

Fig. 5 shows the traffic flow forecasts for one week (Monday to Sunday) and actual measurements as taken during the forecasted time periods. As can be seen, the forecasts match the overall shape of the actual readings, even on weekend days.

Fig. 6 shows the mean per cent error and standard deviation of the traffic flow condition forecasts on different road links in the region of interest and during the near-real-time operational test run. Eighteen ANNs have an average error between 4% and 10% and a median error between 3% and 7%, while the other two ANNs have significantly larger errors. These two ANNs exhibited adequate outputs while the street induction loop data suddenly changed dramatically. As a result, the error, measured as the difference between forecasted and actual, increased accordingly. On closer inspection of the corresponding near-real-time data feeds it became apparent that these experienced some sort of fault, providing flow data that were outside the road links flow capacity limits. Interestingly, the overall iTRAQ performance for the periods where the system got this suspicious data showed no significant change in the quality of the outputs, confirming the robustness of the iTRAQ system architecture.

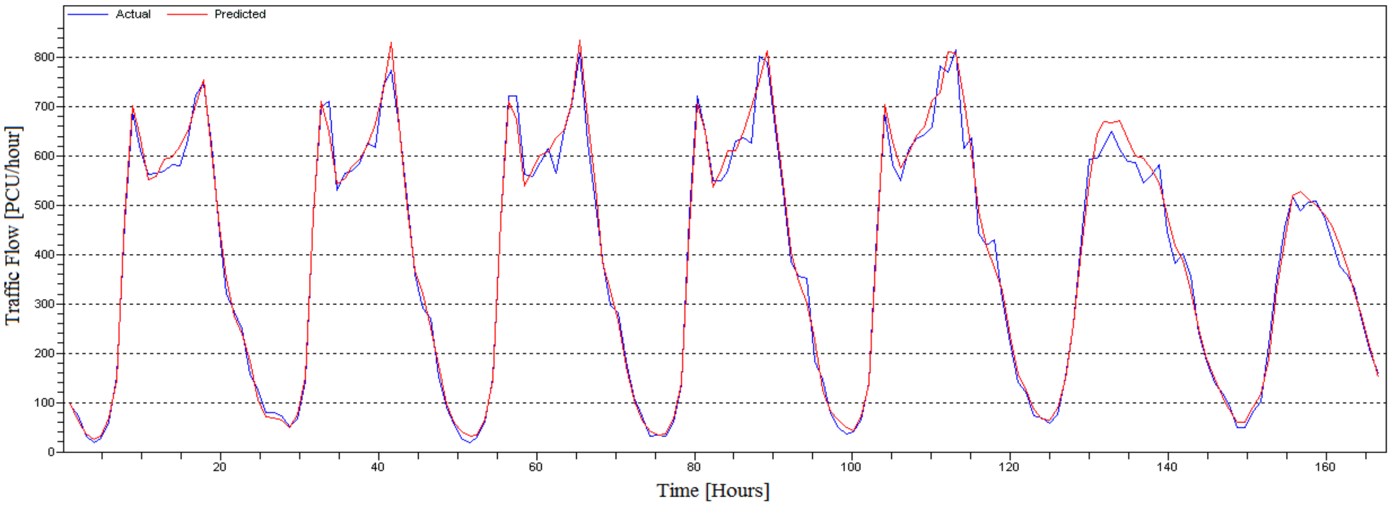

Figure 5. Graph of traffic flow condition forecasts (for one hour ahead) for one week (Monday to Sunday) together with actual measured readings from the forecasted time period. Forecaster based on large training data set. Forecast and data are from the A6 London Road. Average error: 18.9 Passenger Car Units (PCU)/hour.

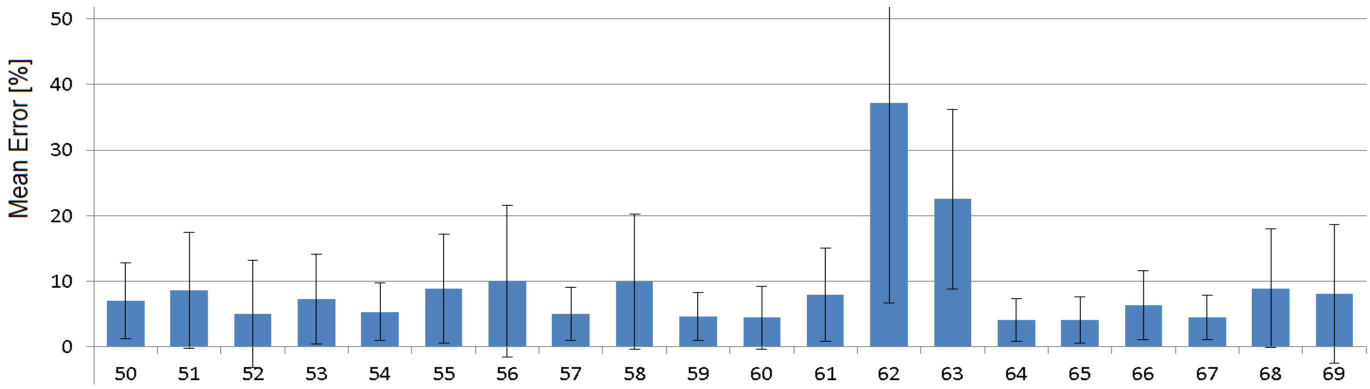

Figure 6. Mean per cent error and standard deviation of traffic flow condition forecasts of 20 road links (IDs 50 to 69) in the region of interest and during the near-real-time operational test run. Note the high error on two links, caused by faulty readings from the induction loops.

C. *Air Quality Forecasts*

Fig. 7 shows the NO_2 concentration forecasts for one week (Monday to Sunday) together with Airviro modelled pollution nowcasts taken during the same time period. Here, as before with the traffic flow condition forecasts, the overall shape of the predictions seem to match, while occasionally somewhat larger errors are visible throughout.

A look at the mean per cent error and standard deviation of the air quality forecasts from the near-real-time operational test run (Fig. 8) shows a slightly different picture. The forecasts on all road links within the region of interest show a mean per cent error of less than 25%, with the best mean per cent error of less than 19%. The main difference between Fig. 7 and Fig. 8 is that for the latter only a fraction of the training data was used: 3 weeks of training data compared to 3 months for the former.

D. *iTRAQ Proposed Strategies*

The near-real-time iTRAQ system successfully supplied traffic engineers with traffic and air quality forecasts and proposed traffic light signalling strategies that in simulation optimised the traffic and air quality throughout the region of interest concurrently.

Fig. 9 presents the mean and median per cent improvement in traffic flow, delay, and pollution levels (AQ) over all near-real-time operational hours of all test days and over all road links in the region of interest. It should be noted that these results are obtained optimising only two junctions in the region of interest.

There is a clear reduction in the mean traffic delay of over 3%. In addition, the optimised strategies offered an increase in traffic flow 89% of the time with a mean increase in traffic flow of 0.6%. An increase in flow means that more cars can get through the network in the same amount of time. The reduction of delay together with the increase in flow presents a reduction of average journey time.

The same figure also shows a small increase in mean pollution levels. The strong decrease in delay directly decreases the fuel consumption and thus a decrease of pollution levels can be observed. At the same time, an increase in flow has the opposite effect, increasing fuel

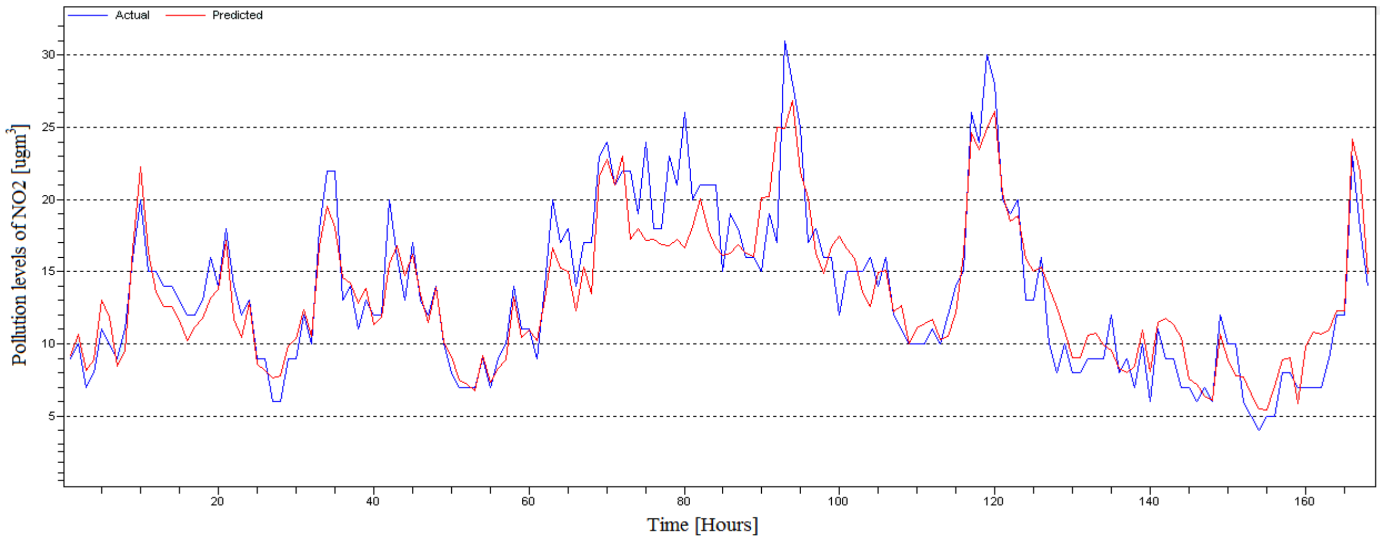

Figure 7. Graph of pollution forecasts (for one hour ahead) for one week (Monday to Sunday) together with actual Airviro readings from the forecasted time period. Forecaster based on large training data set without EO background field data. Forecast and data are from the A6 London Road. Average error: 1.6 ugm^3.

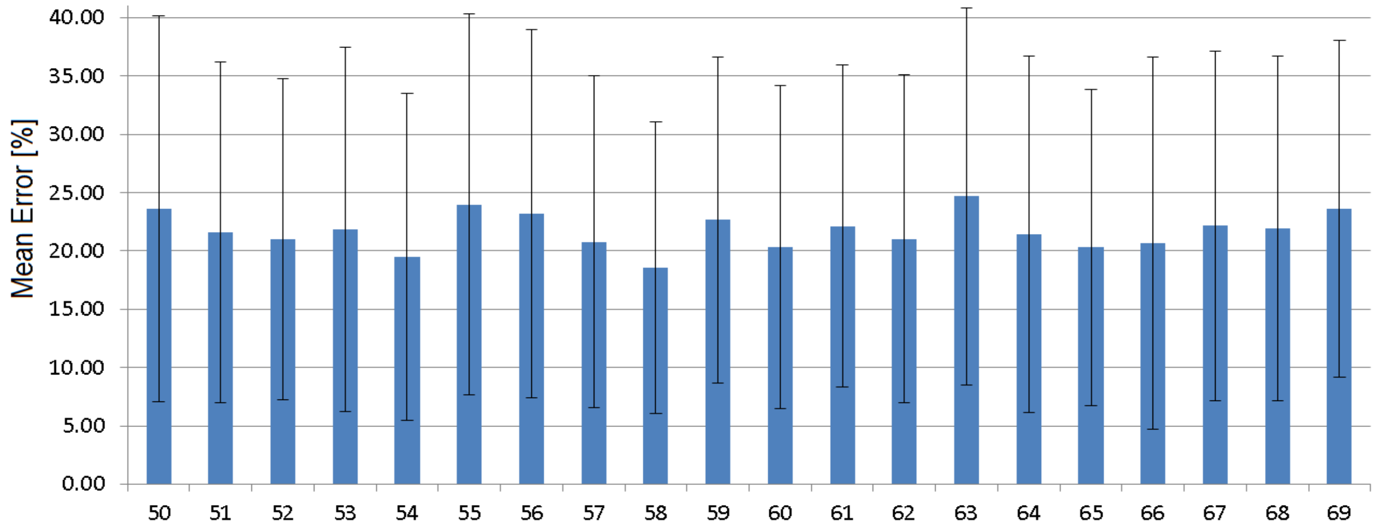

Figure 8. Mean per cent error and standard deviation of air quality forecasts of 20 road links (IDs 50 to 69) in the region of interest and during the near-real-time operational test run.

consumption and pollution levels. Both decrease in delay and increase in flow are the reason for the small change in pollution levels. Nevertheless, Leicester City Council's traffic engineers confirmed this to be a positive result as an increase in flow effectively reduces the overall peak duration and thus reduces the duration of the pollution peak as well. In addition, it should be mentioned that these average measures do not show the individual increases and decreases of all links in the region of interest. An increase in pollution levels on a lightly polluted road may match the decrease in pollution levels on a highly polluted road, which the mean would not show. Therefore these results will have to be analysed in more detail in the future.

The system has been tested 07:00 to 17:00 thus including AM and PM peaks as well as the complete inter-peak period. The small standard deviation and similar results on the

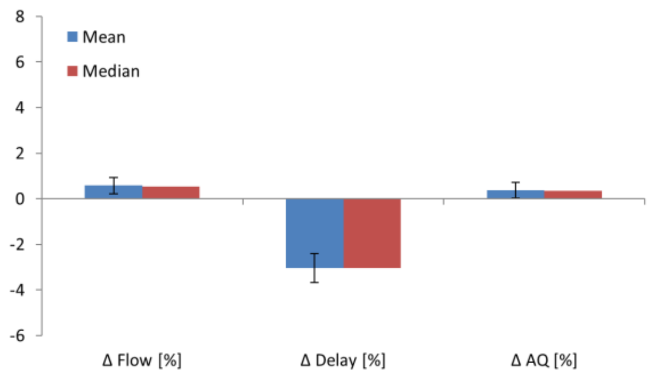

Figure 9. Mean and median per cent improvement in traffic flow, delay, and pollution levels (AQ) over all operational hours and all near-real-time operational test days.

median measures confirm the system's consistency in proposing better traffic management strategies in simulation.

The presented results have been achieved using only two neighbouring junctions within the much larger region of interest. Generally, the more junctions are simultaneously optimised the better the improvements may be.

VI. Conclusions

In this paper we introduced the iTRAQ concept, providing details on the operational system for integrated traffic management and air quality using space services. Results from an in-depth feasibility study have been presented.

We can conclude that the iTRAQ system is capable of integrating decision-making on both air quality and traffic and that it is operationally feasible, using traffic condition data from in-situ road loops (which will be replaced by GNSS data in the future), and air quality information, informed by EO data via a modelling mechanism such as MACC.

The iTRAQ system provides the user with a variety of additional information, such as forecasts of traffic conditions and pollution levels, in order to react to this information and make more informed decisions even before traffic congestion or pollution levels build up.

Within the feasibility study, a system which runs reliably was demonstrated for several days, despite certain data input instabilities.

The computational Intelligence based forecasters demonstrated their ability to forecast traffic flow based on the iTRAQ inputs provided. Eighteen out of twenty traffic forecast ANNs performed with a median error of 8.5%. The other two were corrupted due to false readings from traffic loops. The ANN-based pollution forecaster demonstrated an ability to learn from its input data. The forecasts showed a mean per cent error of less than 25%. These results can be considered adequate for the purpose of enhancing traffic management decision making. Nevertheless, the iTRAQ NRT system's ANN-based forecasts were limited to a minimal amount of training data. It was shown that with an adequate amount of training data, the system can forecast flow as well as pollution levels in much greater accuracy.

With these forecasts, the computational intelligence core module was able to efficiently provide enhanced traffic management strategies. The demonstration system developed offered an increase in traffic flow 89% of the time (with an average increase of 0.6%) and a reduction of delay every time (average reduction of over 3%) using only two neighbouring junctions (out of 25 in the region of interest alone). The benefits demonstrated in the feasibility study would be significantly augmented once integration of multiple junctions was incorporated into a CI algorithm, permitting offsets between light timing to be optimized.

The modular nature of the iTRAQ architecture makes it a simple matter to adapt the system to a variety of possible data sources. Most raw traffic data, pollution level data, and met data, even in unusual combinations are supported.

Daily data from satellites such as OMI are currently available for use in systems such as iTRAQ or MACC, with NRT products available approximately 3 hours after acquisition. Direct use of satellite-measurements of nitrogen dioxide or aerosol optical depth from the current generation of LEO satellites are unlikely to be of use in systems such as iTRAQ, given the single daily measurement, the prevalence of cloud cover, and the 3 hour delay between image acquisition and data availability.

Mechanisms such as MACC offer significant capability through large-scale modelling of air quality, permitting improved forecasting of potential import. Incorporation of background concentrations from MACC improves agreement between air quality modelling and measured air quality from in situ sensors. MACC, incorporating EO data, improves the ability of traffic-derived models to predict air quality and may therefore be a tool for future systems for urban management.

The iTRAQ consortium is currently testing the iTRAQ system in a new environment (Northampton, UK), on a much larger region of interest, and integrating GNSS traffic condition data into the iTRAQ system. Following a successful feasibility study, a larger demonstration phase is now being planned and other local authorities are being encouraged to participate.

Acknowledgment

The authors would like to thank the European Space Agency and the East Midlands Development Agency - Transport iNet ERDF for funding the iTRAQ and iTRAQ –X projects, and Leicester City Council, Leicestershire County Council, and Northampton City Council for providing data and support for the project. The efficient provision of NO_2 surface data by the MACC project team is also gratefully acknowledged.

References

[1] J. Cheese and B. Radia, “UTMC programme overview: Emerging results, communication standards and the demonstration projects,” in Tenth International Conference on Road Transport Information and Control, no. 472, 2000, pp. 143–146.

[2] B. Radia, “Integrating the traffic management applications of ITS: An overview of the UTMC programme in the UK,” ITS Journal, vol. 6, no. 1, pp. 83–90, 2000.

[3] Urban Traffic Management and Control, UK Department for Transport (DfT), “Integration in action, urban traffic management and control,” http://www.utmc.uk.com/news/pdf/UTMC Flyer1 A4 - Traffex09Final.pdf, 2009.

[4] M. Papageorgiou, C. Diakaki, V. Dinopoulou, A. Kotsialos, and Y.Wang, “Review of road traffic control strategies,” Proceedings of the IEEE, vol. 91, no. 12, pp. 2043–2067, 2003.

[5] J. Garcia-Nieto, E. Alba, and A. Carolina Olivera, “Swarm intelligence for traffic light scheduling: Application to real urban areas,” Engineering Applications of Artificial Intelligence, vol. 25, no. 2, pp. 274–283, 2012.

[6] M. G. H. Bell, Transport Planning and Traffic Engineering. Butterworth-Heinemann, Nov 1996, ch. Signal Control in Networks, pp. 506–516.

[7] J. Hu, C. Zong, J. Song, Z. Zhang, and J. Ren, “An applicable short-term traffic flow forecasting method based on chaotic theory,” in 2003 IEEE Intelligent Transportation Systems Proceedings, VOLS. 1 & 2, pp. 608–613, 2003.

[8] L. Zhang, L. Jia, and W. Zhu, “A review of some intelligent optimization algorithms applied to intelligent transportation system,” Advanced Materials Research, vol. 383, pp. 5717–5723, 2012.

[9] S. Ishak and C. Alecsandru, “Optimizing traffic prediction performance of neural networks under various topological, input, and traffic condition settings,” Journal of Transportation Engineering, pp. 452–465, July/August 2004.

[10] Review of the UK Air Quality Index, A report by the Committee on the Medical Effects of Air Pollutants [COMEAP], 2011.

[11] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Volume 2, Defra, 2007.

[12] House of Commons Environmental Audit Committee, Air quality: A follow up report, ninth report of Session 2010-12, Volume 1, 2011.

[13] S. Beevers et al, Air pollution and emission trends in London, King’s College London report to Defra, 2009

[14] G. Fuller and D. Green, Evidence for increasing concentrations of primary PM10 in London, Atmos. Environ., 40, 6134-6145, 2006

[15] M. Agarwal, T. Maze, and R. Souleyrette, “Impacts of weather on urban freeway traffic flow characteristics and facility capacity,” in *The 2005Mid-Continent Transportation Research Symposium*, 2005.

[16] N. Hodges, “Sustainable Use of Intelligent Transport Systems in Leicester, UK”, Proceedings of the 7th World Congress on Intelligent Systems, 2000.

[17] P. Zito, H. Chen and M. C. Bell, “Predicting Real-Time Roadside CO and NO_2 Concentrations Using Neural Networks”, IEEE Transactions on Intelligent Transportation Systems, vol. 9, pp. 514-522, 2008.